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A PRELIMINARY INVESTIGATION OF A NEW METHOD FOR TESTING AEROFOILS IN FREE FLIGHT.

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SUMMARY.

This report is a description of a new method of testing aerofoils in free flight devised by the National Advisory Committee for Aeronautics. The method consists in lowering below a flying airplane a large inverted aerofoil on three small steel wires in such a way that the lift on the aerofoil always keeps the wires tight. The resultant force is measured by the tension in the wires, and the direction of the resultant by the amount the wing trails backwards. A test was made on an aerofoil of the N.A.C.A. #64 section, 6 ft. in span and the results are compared with a similar section tested in the wind tunnel. This investigation indicates that by the use of suitable recording apparatus aerofoils may be accurately and conveniently tested at a Reynolds number, a velocity and a degree of turbulence, comparable with that on the full-sized airplane. Satisfactory experiments were also made in trailing a sphere and a streamlined body on single wires.

Introduction.

From the very beginning of the science of aeronautics there has been desired a satisfactory method for making tests on aerofoils and other aerodynamic bodies under the identical conditions of their use on the airplane. The wind tunnel and the whirling arm will give velocities equivalent to those of flight but the size of the wings that may be tested in this way is only a tenth or twentieth part of the full-sized ones. Attempts have been made to test full-sized wings when mounted upon a car or automobile but due to the interference of the ground and to irregular winds the results have not been satisfactory and these methods have now been practically abandoned.

An attempt is made here to provide a method for testing full-sized, or nearly full-sized aerofoils at airplane speeds and under the same conditions of turbulence that are encountered by the airplane. The present investigation is of course only of the most preliminary character, so that the accuracy of the result is not high. The method however has been carefully studied, especially in regard to its inherent errors and the time required for making tests. Sufficient experience has been gained to justify the design of a new balance for use on a larger airplane.

Methods and Apparatus.

The apparatus used for measuring the tension in the supporting wires is shown in Fig. 1. A heavy steel tube passes laterally through the fuselage and is connected by a pair of levers to a spring scale on the instrument board. On the center of the tube a windlass is attached for reeling up the wires passing to the wing. The two forward wires run outward from the windlass over pulleys at the end of the tube while the third wire runs backward and down through the fuselage. The angle of attack of the wing is changed by reeling in or out the rear wire while the others are held stationary.

The angle at which the wing trails back is measured by means of a reading telescope mounted on the side of the fuselage with a graduated circle. The vertical is indicated by means of a small pendulum. The pendulum although only slightly damped was very steady and would seem to be a very satisfactory method of indicating the vertical in uniform flight.

The angle of attack of the wing itself is measured by placing on the wing surface a liquid inclinometer which is viewed through the same telescope as used for measuring the angle. In this test the readings of the angle of attack were rather unsatisfactory due to the length of the bubble and to insufficient damping of the liquid; so the fluctuations were at all times considerable. Much better results can be obtained by measuring the angle of attack in the cockpit from the length of the wires.

The first aerofoil constructed was of solid white pine, and a few runs were made with it. As the weight of this aerofoil was considerable and as it was feared that it might do considerable damage to the airplane should it reach an angle of negative lift, it was considered safer to construct another one of light wood and fabric in the same manner as the usual type of airplane wing (Fig. 2). The forward wires are attached to the leading edge of the wing and the third wire is attached to the rear end of a wooden boom running backwards for about 5 ft. On the forward end of this boom there is a small vertical fin and at the rear end a large aluminum rudder, both for the purpose of giving directional stability. The area of these surfaces is probably much larger than there is any need of and wind tunnel tests will be made in order to determine the minimum size that may be used. The size of the boom is also much larger than required and its resistance can be at least halved.

When taking off and landing, the wing is drawn up close against the under side of the fuselage, a hole being cut in the fabric to take the upper part of the fin. When the airplane has reached a sufficient altitude it is throttled down to about 45 miles an hour and the windlass is slowly unwound; the angle of attack being gradually increased in order to correct for the change in direction of the air flow as the wing is lowered below the influence of the downwash. Incidentally, the angle and velocity of the air flow can be studied for any distance above or below a flying airplane by means of a trailing aerofoil. After the wing has reached the desired distance below as determined by a mark on one of the wires the airplane is held at exactly sixty miles per hour and readings are taken on the balance and with the telescope for various angles of attack. No difficulty at all is experienced in making turns with the wing hanging down, although no banks greater than 20° were attempted. Several runs were made with the wing in extremely bumpy air and although the wing swings around considerably, mainly in a lateral direction, there appeared to be no danger of its getting out of control; but in making accurate tests it is quite essential that the air be smooth. After a test has been completed the wing is reeled up against the fuselage. Care has to be taken when gliding down to the field not to reach too great an air speed for the force on the wings may become dangerously large. Over twenty flights were made with this wing, the piloting being done throughout by Mr. T. Carroll of the Committee's staff.

Throughout the conduction of the tests it is necessary for the observer to use the utmost care that the lift on the wing does not reach such a small value that it can not be balanced by the weight of the wing itself. When using larger aerofoils than this one there would be great danger in such an occurrence as the fuselage or tail surfaces would very probably be seriously crippled. This danger can be guarded against by having an electrical contact on the balance set so that when the pull in the wires decreases below a certain safe value the angle of attack will be automatically increased.

The lift and drag on the aerofoil are given by the following expressions where θ is the angle of trail from the vertical, W is the weight of the wing, D_1 is the effective resistance of the wires and supporting boom, and R the pull in the wires:

$$L = R \cos \theta - W$$

$$D = R \sin \theta - D_i$$

Precision.

The factors which enter into the computation of the lift and drag of the wing are the air speed, the tension in the wires, the angle of trail, and the resistance of the wires and boom. An experienced pilot can easily hold an airplane within one mile an hour of the given speed when the air is smooth, but if the air speed reading is recorded with each reading of the balance even a greater variation than this is of little importance. By calibration over a speed course it should be possible to measure the air speed of the plane to within ± 0.5 mile per hour. If we fly, for example, at 60 miles an hour this will introduce an error into the force readings of $\pm 1.5\%$.

The tension in the wires, as far as the balance itself goes, can be measured as closely as desired, the limit of accuracy being the steadiness of the load. In these experiments it was found that the spring balance vibrated quite rapidly over a range of from 5 to 10% of the absolute reading although a mean reading could be taken to the nearest pound. It is thought that this vibration can be greatly reduced by using a suitable dash pot in the system. There is little doubt that the value of the resultant can be read to within one pound of its true value under all conditions.

The angle at which the wing trails back from the vertical may vary between 5° to 20°, according to the L/D of the aerofoil.

It might be thought that a wing supported on wires 30 or 40 ft. below the airplane would make severe oscillations but when the air is smooth the wing remains so steadily in one place that it is almost impossible with the eye alone to detect any relative motion with the airplane. When the telescope is used a slight oscillation can be observed but this is so small and so regular that there is no trouble in obtaining a mean reading of the angle to 0.2°. An error of 0.2° in the trail angle will introduce an error in the drag of about 3% when the L/D is at a high value.

The method of measuring the angle of attack in this experiment was rather unsatisfactory as the fore and aft oscillations of the wing, although small, produced a considerable longitudinal acceleration on the wing which made the bubble in the inclinometer vibrate back and forth over several degrees; so that an estimation of the angle of attack was quite difficult. It is believed that much better results can be obtained by calibrating the windlass in such a way that the angle of attack can be directly read from the cockpit. This would have the advantage in that it would allow the observer to set the angle to definite values each time. The angle of attack however is not of primary importance and, even if it was found that it could not be determined with accuracy, it would not greatly reduce the value of the test.

Another source of error which may be serious if care is not taken is the vertical direction of the flight path. By the careful use of a sensitive statoscope, levels should be maintained good to within 20 ft. in a mile which represents about 0.2°. Larger errors than this however may be introduced due to the rising and falling currents which are often present in the atmosphere. It seems probable however that rising and falling currents occur only when the air is bumpy, and as tests can not be made in bumpy air, it does not seem as if the errors due to rising and falling current would be troublesome. It is always advisable to fly these tests either early in the morning or just before sunset, as the air at these times is almost sure to be smooth.

The true drag of the wing is the difference between the total drag of wing and supports, and the supports alone. It is evident that the greater the resistance of the supports compared with that of the wing, the more accurately must all measurements be made. It is probable that the resistance of the supports in free flight can be cut down to one-half the minimum drag of the wing. This is as small a proportion of support drag as is usually obtained in wind tunnel tests.

The drag of the wires and boom may be determined either by a wind tunnel test or by trailing them in flight. The latter method has been tried out and no difficulties were encountered. The interference between the boom and wing may be considerable and should be measured in the wind tunnel on a model.

Results on the N.A.C.A. #64 Aerofoil.

A 12-inch by 72-inch aerofoil as described above was mounted on the airplane and a test was made with the wing about 20 ft. below the balance. The two forward supporting wires were each .022 inch in diameter while the rear wire was .015 inch in diameter. The drag of the wires and boom was measured by lowering the boom and wires alone and measuring the angle at which they trailed back at 60 miles an hour. In order to get the correct angle of trail the boom was constructed partly of lead. The oscillations of the boom were slightly greater than for the wing but a mean reading could be taken with considerable accuracy. The resistance of the boom and wires which varied of course with the angle of attack, amounted to two pounds at zero angle, which is approximately equal to the minimum drag of the wing itself. In this test no attempt was made to obtain the interference between the boom and the wing, therefore the drag as read is probably somewhat high, which probably accounts for the abnormally high L/D measured for this section. The actual time required in taking the readings on the wing (Fig. 3) was not over 10 minutes, and the time in the air (two flights) not over 30 minutes.

The results for this section are plotted in Fig. 3, together with the test of a model of the same aerofoil in the wind tunnel. It will be noted that the lift curve although parallel to the model curve is considerably higher at all points. Except in a few cases, the observed points lie fairly closely to their curve. The drag curves lie very close together although the free flight values are somewhat lower at low angles of attack. Both the lift and drag curves show that the angle of attack in free flight was probably somewhat in error and that both curves should be shifted about a degree to the right. The maximum L/D in free flight is rather high, reaching a value of 21 as compared to 16 for the model test. While the increase in scale would be expected to increase the L/D to a considerable degree the free flight curve is probably too high due to the fact that the interference between the boom and the wing was not taken into account. These results are only of the most preliminary nature and no pretense is made for accuracy, but it is believed that rough as they are they demonstrate clearly the feasibility of this method.

Tests of Spheres and Streamlined Bodies.

In order to investigate the possibilities of measuring the drag of bodies in free flight, a bomb-shaped model and a sphere were each let down below the airplane on a single wire. The bomb oscillated considerably after changing speed or after turning; but if steady conditions were held it appeared as steady as the aerofoil. The sphere was equally steady and even though the test was made on a bumpy day, the trail angle of 18° could be read to 0.5° with ease. There seems to be no reason why the resistance of spheres up to 3 or 4 ft. in diameter can not be measured in this way with a high degree of accuracy. Unfortunately the time was not available for making any actual measurements with these bodies, but it is hoped that extensive work of this kind can be carried out in the near future.

Conclusion.

The results from this investigation demonstrate that it is possible to make tests on large wings in free flight with a considerable amount of ease and accuracy. It is recommended that further work be carried out along this line on an airplane of greater capacity and on wings of larger size. In this connection a balance should be designed which will automatically record the air speed, the force on the wires, and the angle of trail for each angle of attack. It would also be advisable to record the force on the rear wire separately so that the moments of the wing could be determined. On the larger wings it will also be necessary to provide a power windlass for lowering and pulling up the wing and as suggested before an electrical safety device to prevent the wing from getting a negative loading. It is believed that if such a balance and apparatus is designed, wings of 30 ft. span and 5 ft. chord can be tested as quickly and accurately at a speed of 100 miles an hour as a small model can now be tested in the wind tunnel.

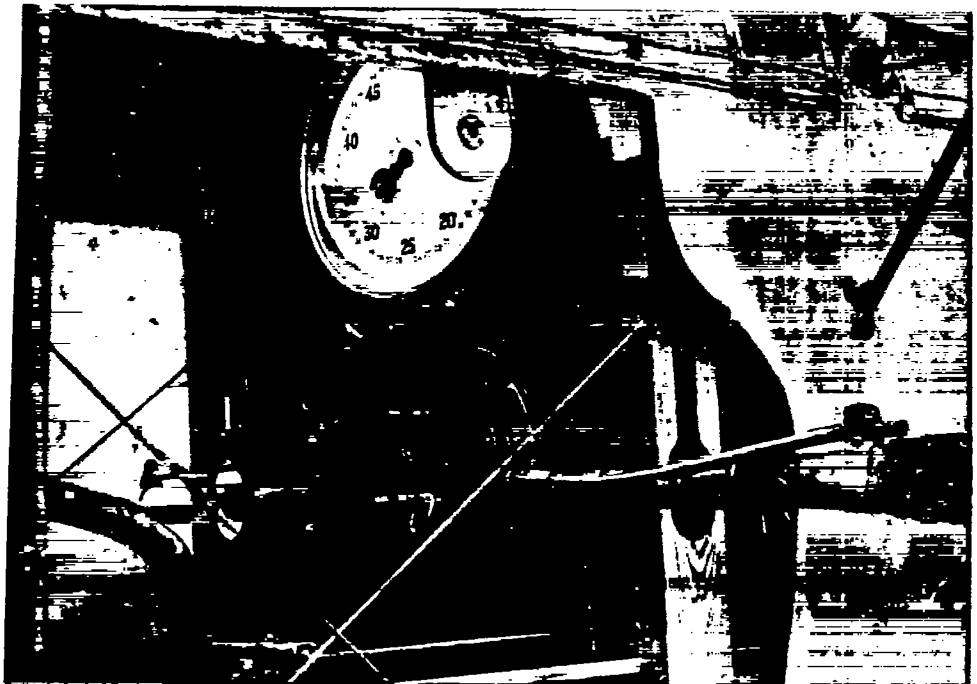


Fig. 1 View of balance assembly
(Fabric stripped from fuselage)

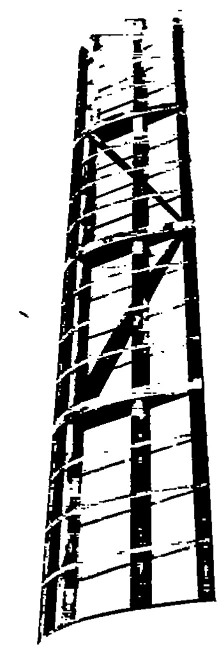
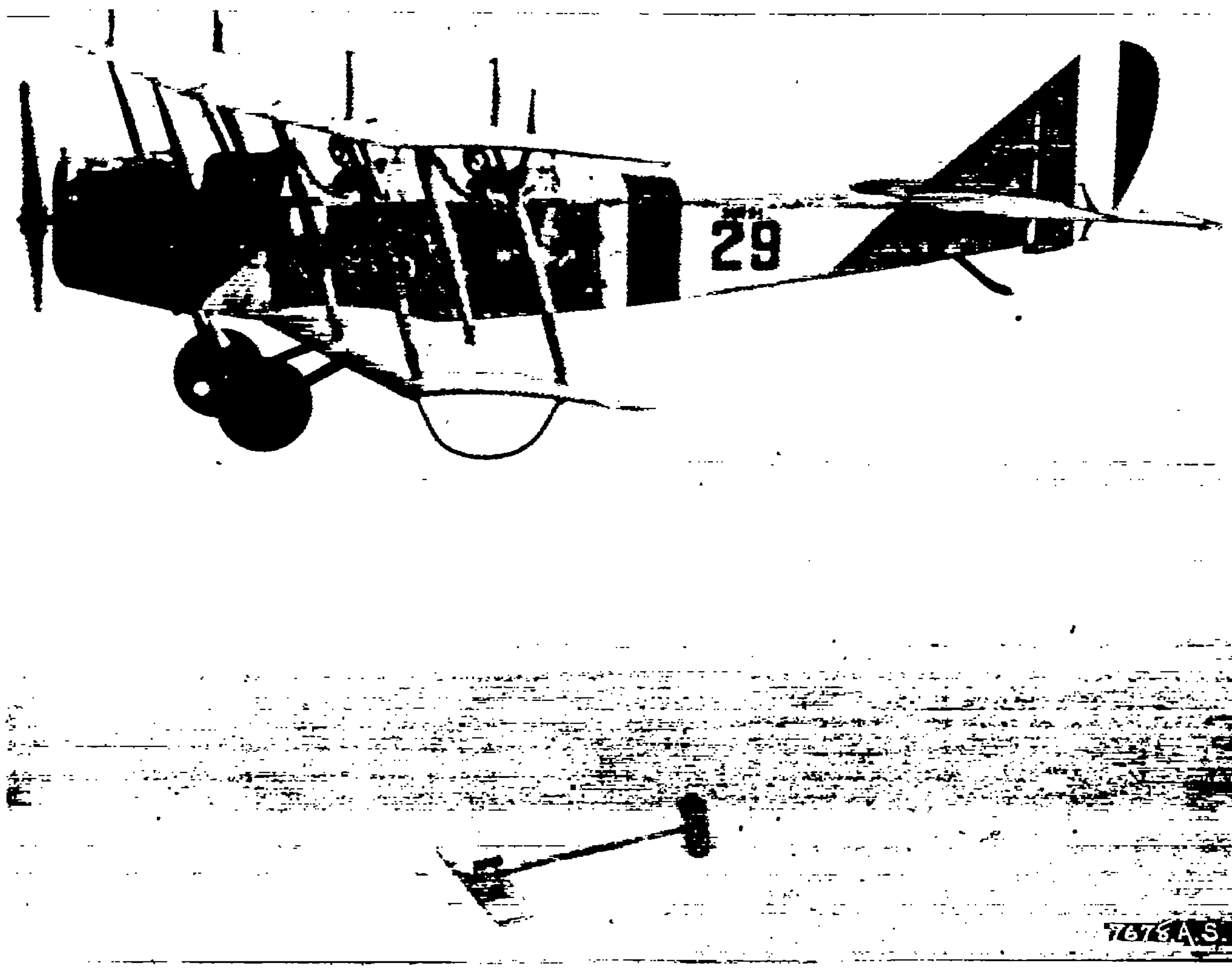


Fig. 2 Aerofoil before covering



A Trailing wing in flight

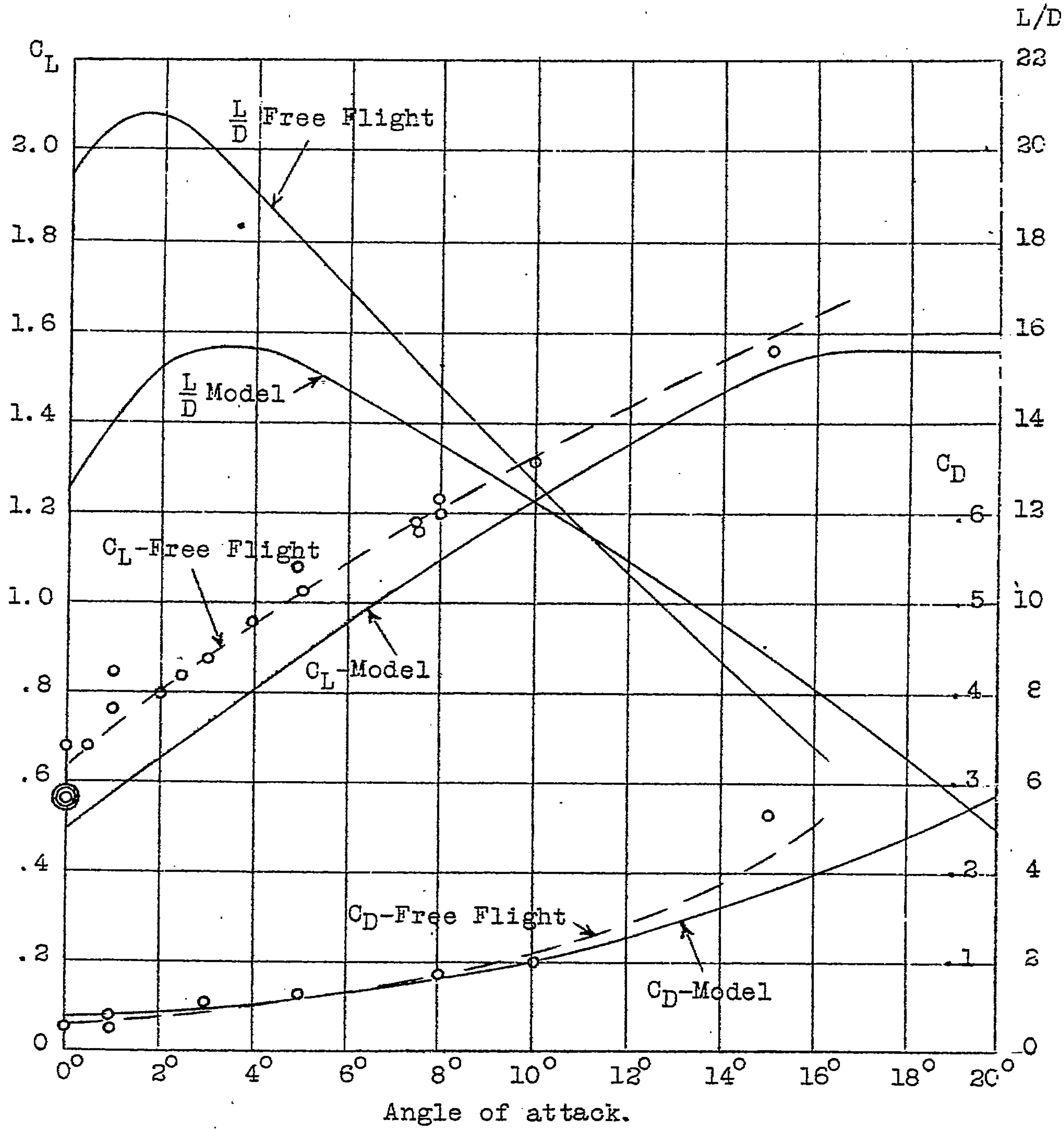


Fig. 3.
Comparison of Model and Free Flight Tests of N.A.C.A. #64 Section.
Model 3" x 18" at 30 m.p.s.
Free Flight 12" x 72" at 60 M.P.H.